# Properties of Low Activity Clay Soils from South Kalimantan

*Sifat-sifat dari tanah berliat aktivitas rendah di Kalimantan Selatan*

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## ABSTRAK

Tanah berliat aktivitas rendah adalah salah satu tanah bermasalah di Indonesia. Jenis tanah ini meliputi tanah-tanah Ultisols, Oxisols, Alfisols, dan sebagian Inceptisols, mencakup sekitar 34,5% dari total daratan Indonesia, dan berkembang dari bahan induk yang beragam. Untuk mengevaluasi sifat-sifat tanah berliat aktivitas rendah, 6 pedon tanah (Oxisols dan Inceptisols) yang berkembang dari batu liat, batuan andesit, batuan ultra basis dan batu gamping, di daerah Kalimantan Selatan telah diteliti di lapangan maupun di laboratorium. Analisis laboratorium meliputi tekstur, kandungan bahan organic, pH ($H_2O$ dan KCl), P dan K potensial, ketersediaan P, retensi P, basa-basa dan kemasaman dapat tukar, kapasitas tukar kation, dan komposisi mineral. Hasil penelitian menunjukkan bahwa tanah berliat aktivitas rendah didominasi oleh mineral opak dan kuarsa sebagai mineral primer yang resisten. Fraksi liat didominasi oleh kaolinit, dan dalam jumlah yang jauh lebih sedikit dijumpai pula goethite, hematite, dan gibsit. Komposisi mineral dari tanah-tanah berliat aktivitas rendah mengindikasikan rendahnya cadangan sumber hara dalam tanah dan tingkat pelapukan tanah yang sudah lanjut. Dari sudut sifat kimianya, tanah-tanah berliat aktivitas rendah bersifat masam, mempunyai konsentrasi basa-basa dapat tukar dan kapasitas tukar kation yang rendah, serta mempunyai retensi fosfat dan kejenuhan aluminum yang tinggi. Pemupukan yang lengkap diperlukan untuk penggunaan yang berkelanjutan. Penambahan bahan organik lebih penting pada tanah berliat aktivitas rendah Oxisols bila dibanding Ultisols, tapi pengapuran lebih penting pada tanah berliat aktivitas rendah Ultisols. Walaupun kendala kesuburan tanah dapat diatasi dengan pengapuran dan pemupukan yang lengkap, kondisi sosial ekonomi dari petani masih merupakan kendala tersendiri.


*Kata kunci : Liat beraktivitas rendah, Oxisols, Inceptisols, Kalsel*


## ABSTRACT

Soils with low activity clay is one of the problem soils in Indonesia. These soils consisted of Ultisols, Oxisols, Alfisols, and some Inceptisols, occupied about 34.5% of total Indonesian land, distributed in almost all Indonesian islands, and derived from various parent materials. To evaluate the properties of low activity clay soils, 6 pedons of Oxisols and Inceptisols, derived from clay stone, andesitic rock, ultra mafic rock and lime stone, from South Kalimantan were studied both in the field and in the laboratory. The analyses consisted of texture, organic carbon content, pH ($H_2O$ and KCl), potential P and K, available P, P retention, exchangeable bases and acidity, cation exchange capacity and mineralogical composition. The results showed that low activity clay dominated by opaque and quartz as primarily resistant mineral. Clay fraction was dominated by kaolinite, and to a lesser extent goethite, hematite, and gibbsite were also present. The mineralogical composition of the low activity soils indicated a low natural potential nutrient reserve and an advanced stage of soil weathering. Chemically, the low activity clay soils were acid, low content of bases, low cation exchange capacity, high P retention, and some of them show a high aluminum saturation. A complete fertilizer application is necessary for a sustainable use. Although soil fertility constraints on the low activity clay soils can be corrected by liming and appropriate fertilization, socioeconomic condition of the local farmer is another constraint.


*Key words : Low activity clay, Oxisols, Inceptisols, South Kalimantan*

## INTRODUCTION

The term low activity clay (LAC) is used merely for the purpose of management for the majority of upland soils in the humid and sub humid tropics (Kang and Tripathi, 2002). LAC has been widely accepted to group soils with cation exchange capacity (CEC) less than 24 cmol(+)$kg^{-1}$clay as measured by the $NH_4OAc$ method (Isabel, 1980; Juo,1980).

Indonesian soil scientists prefer to classify the LAC soils as Ultisols, Oxisols, Alfisols, and Inceptisols according to USDA Soil Taxonomy system (Sudjadi, 1984), however, some of them are still using Dudal and Soepraptohardjo system (1957) by naming those soils as Podzolic, Latosol, and Lateritic soils or just red soils. These soils occupy a great part of Indonesia, and they were formed from both felsic and mafic rocks. Among the Indonesian LAC soils, Ultisols are the most widespread and occupy approximately 25.7% of the Indonesian land surface, while other LAC soils occupy about 5% (Biro Pusat Statistik, 1987; Driessen and Soepraptohardjo, 1974). The latest data from Subagyo *et al.* (2000) mentioned that Ultisols, Oxisols, Alfisols, and Inceptisols occupy 24.3, 7.5, 2.7, and 37.5% of the Indonesian land surface, respectively.

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LAC Ultisols, Inceptisols, and Oxisols were previously were called as Red-Yellow Podzolic soils, lateritic soils or Latosol. They occupy upland areas in Sumatra, Kalimantan, Sulawesi, and Papua island, and most of them were developed from sedimentary rocks, especially clay stone and sandstone (Subagyo *et al.,* 2000). These soils are generally characterized by low nutrient content, low CEC, low pH, high exchangeable aluminum, high P fixing capacity and high content of 1:1 and oxide minerals (Goenadi, 1985).

The LAC soils have an important role in agriculture, especially for secondary food crops and estate crops. Most of these soils are dry land and located in low plain. About 35.5 million ha of the soils in low plain are potential for secondary crops (such as soybean and maize) development (Hidayat *et al.,* 2000). This paper aimed to discuss the properties of LAC soils especially in their mineralogical composition and chemical properties.

## MATERIALS AND METHODS

The study was conducted in South Kalimantan from 1999 to 2000. During the fieldwork, 6 soil pedons (Table 1) from various parent materials were observed, and soil samples representing 32 soil horizons were taken for laboratory analyses. According to Suharta *et al*. (2000), the soils were classified as Inceptisols and Oxisols. The Inceptisols were Oxic Dystrudepts (P1 and P3), while the Oxisols were Typic Hapludox (P2), Typic Kandiudox, (P6) and Anionic Acrudox (P4 and P5). The parent materials of the LAC soils were clay stone (P1and P3), andesitic rock (P2), ultra mafic rock (P4), and lime stone (P5 and P6). All of the pedons were situated in a tectonic plain.

In the laboratory of Center for Soil and Agroclimate Research, Bogor the soil samples were analyzed for physic-chemical properties and mineralogical composition. The physic-chemical analyses included particle size analysis, organic carbon, pH ($H_2O$ and KCl), exchangeable cation and cation exchange capacity (CEC) by 1 N $NH_4OAc$, pH 7 extraction, exchangeable acidity by 1 N KCl, available phosphate (P) by the Bray-I method, potential P and K by 25% 1N HCl, P-retention by the method of Blackmore *et al*. (1981), and free iron by sodium dithionite extraction. All other soil property analyses were conducted following the methods described in Soil Survey Laboratory Staff (1991).

**Table 1. Classification, location, elevation, and landuse of LAC soils in South Kalimantan**

*Tabel 1. Klasifikasi, lokasi, ketinggian, dan penggunaan tanah berliat aktivitas rendah di Kalsel*

| Pedon | Classification | Location | Slope and position | Landuse |
|---|---|---|---|---|
| P1 | Oxic Dystrudepts | G. Alat, Kec. Halong, Kab. Hulu Sungai Utara | 21%, upper slope | Low land forest |
| P2 | Typic Hapludox | G. Mamantang, Kec. Halong, Kab. Hulu Sungai Utara | 16%, middle slope | Low land forest |
| P3 | Oxic Dystrudepts | Kelumpang, Kec. Pemukan Selatan, Kab. Kota Baru | 4 %,lower slope | Low land forest |
| P4 | Anionic Acrudox | Brian, Kec. Kelumpang Tengah, Kab.Kota Baru | 14 %, upper slope | Low land forest |
| P5 | Anionic Acrudox | Menggalau hilir, Kec. Sampanahan, Kab. Kota Baru | 3%, lower slope | Bush land |
| P6 | Typic Kandiudox | Tanah Abang, Kec. Kelumpang Hulu, Kab. Kota Baru | 9%,middle slope | Rubber estate |

Mineralogical analyses were conducted on sand and clay fractions. Sand fractions were analyzed by polarizing microscope, while the clay fractions were analyzed by X-ray diffractometer (XRD). In the XRD run, the clay sample was treated with the standard procedure that is saturating the samples with Mg, Mg plus glycerol, K, and K plus then heated at 550°C (Moore and Reynold, 1989; van Reeuwijk, 1993). The dithionite citrate bicarbonate treatment was adopted for clay fraction in order to obtain best performance of x-ray diffraction pattern. Sand minerals were analyzed only for selected pedon, such as pedon P1 (claystone), P2 (andesitic rock), P4 (ultra mafic rock), and P5 (limestone).

## RESULTS AND DISCUSSIONS

### Mineralogical composition

Mineralogical composition of sand fraction, represented by pedons P1, P2, P4, and P5 (Table 2), is an important indicator regarding type of parent material and stage of weathering, as well as potential nutrient reserve of the soils.

The mineralogical composition of all pedons but P5 was dominated by resistant primary minerals such as opaque and quartz. The kind of mineral in the sand fraction was almost the same, but the amount in every pedon was quite different. The LAC soils developed from clay stone (P1) were composed predominantly of quartz and rock fragments. The rock fragment was a fragment of sand consisting of several minerals which were unable to be identified by polarizing microscope. Soil developed from andesitic rock (P2) was dominated by opaque and rock fragments, soil developed from ultra mafic rock (P4) was dominated by opaque minerals, and soil developed from limestone (P5) was dominated by combination of weathered mineral, iron concretion, quartz, and opaque minerals.

All pedons are dominated by resistant primarly mineral, such as opaque and quartz. Almost no fresh weatherable minerals were found in P1, P2, P3, and P4, but in P5 containing many weathered minerals. The mineral in the sand fraction indicated that an advanced stage of soil weathering has been occured and the potential nutrient reserve of the soils was poor. These findings agreed with other studies who found that sand fraction of LAC soils from Lampung was dominated by quartz and opaque (Prasetyo *et al.*, 1997), while LAC soils from Sanggauledo was dominated by quartz and weathered minerals (Suharta *et al.,* 1995). The results of semi-quantitative determination of the clay mineral composition of the LAC soils are presented in Table 3. Two pedons with X-ray diffraction pattern of the clay fraction are illustrated in Figure 1.

The clay fraction of the LAC soils was generally composed of kaolinite, iron oxide minerals (such as goethite, hematite and magnetite, gibbsite), small amounts of vermiculite, and quartz. This combination of clay mineral composition is very common for LAC soils (Herbillon, 1980; Uehara and Gillman, 1981). This composition is almost the same with soils developed from basaltic rock in West Kalimantan which are dominated by kaolinite and gibbsite (Suharta *et al.,* 1995). Soils derived from acid volcanic tuff in Kotabumi, Lampung are also dominated by quartz, kaolinite, and iron oxides minerals (Prasetyo *et al.,* 1997) and soils developed from granitic rock in West Kalimantan are dominated by kaolinite with small content of vermiculite, illite, and gibbsite (Suharta and Prasetyo, 1986).

Kaolinite is predominant in pedons P1, P2, P3, and P6 but absent in pedon P4 (Table 3). The presence of kaolinite as predominant single clay mineral indicates that the soils have a little or no permanent charge and as a consequence the CEC tends to be low. The absence of kaolinite in pedon P4 could be interpreted that soil weathering in this pedon is more advanced than the other pedons. In nature, kaolinite occurs more commonly as a secondary mineral, and it can be formed as a result of weathering process of primary minerals or derived from other secondary minerals.

**Table 2. Mineral composition of sand fraction of the pedon P1, P2, P4, and P5 of LAC soil from South Kalimantan**

*Tabel 2. Komposisi mineral fraksi pasir pedon P1, P2, P4, dan P5 dari tanah-tanah berliat aktivitas rendah dari Kalsel*

| Depth | Primary Mineral | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Opaque | Quartz | Zircon | Iron concretion | Weathered mineral | Rock fragment | Epidote | Amphibole | Augite | Hypersthen |
| cm | | | | | | | | | | |
| Pedon P1 (from claystone) | | | | | | | | | | |
| 0 – 18 | 5 | 42 | sp | 1 | 2 | 50 | - | sp | - | - |
| 18 – 40 | 5 | 52 | sp | 1 | 1 | 41 | - | - | - | - |
| 40 – 73 | 5 | 46 | - | 2 | 2 | 45 | - | - | - | - |
| 73 – 101 | 4 | 33 | sp | 4 | 3 | 56 | - | - | - | - |
| 101 – 140 | 2 | 35 | - | 2 | 2 | 59 | - | - | - | - |
| Pedon P2 (from andesitic rock) | | | | | | | | | | |
| 0 – 16 | 38 | 11 | sp | 2 | 2 | 47 | - | sp | - | - |
| 16 – 37 | 36 | 5 | sp | 1 | 1 | 57 | - | sp | - | - |
| 37 – 68 | 45 | 7 | sp | 3 | 1 | 44 | - | sp | - | sp |
| 68 – 90 | 57 | 7 | sp | 1 | 1 | 34 | - | sp | - | - |
| 90 – 130 | 54 | 5 | - | 6 | 1 | 34 | sp | sp | - | - |
| 130 – 150 | 58 | 4 | - | 4 | 1 | 33 | - | sp | - | Sp |
| Pedon P4 (from ultramafic rock) | | | | | | | | | | |
| 0 – 11 | 74 | 22 | - | sp | 3 | 1 | sp | - | - | Sp |
| 11 – 40 | 86 | 8 | sp | sp | 4 | 2 | - | - | - | - |
| 40 – 65 | 87 | 8 | sp | - | 4 | 1 | - | - | - | - |
| 65 – 96 | 89 | 7 | sp | sp | 3 | 1 | - | - | - | - |
| 96 – 150 | 91 | 5 | sp | - | 3 | 1 | - | - | - | - |
| Pedon P5 (from limestone) | | | | | | | | | | |
| 0 – 21 | 8 | 11 | sp | 27 | 53 | 1 | sp | - | - | - |
| 21 – 50 | 11 | 11 | - | 18 | 60 | sp | - | - | - | - |
| 50 – 82 | 11 | 11 | sp | 19 | 58 | 1 | - | - | - | - |
| 82 – 123 | 11 | 29 | sp | 15 | 44 | sp | - | - | sp | - |
| 123 – 150 | 9 | 23 | 1 | 14 | 52 | sp | - | - | - | - |

Note: sp = identified from microscope during recheck

**Table 3. Mineral composition of clay fraction of the LAC soils, South Kalimantan**

*Tabel 3. Komposisi mineral fraksi liat dari tanah-tanah berliat aktivitas rendah, Kalsel*

| Depth | Clay mineral | | | | | | |
|---|---|---|---|---|---|---|---|
| | Kaolinite | Vermiculite | Gibbsite | Iron oxide minerals | | | Quartz |
| | | | | Hematite | Goethite | Magnetite | |
| cm | | | | | | | |
| Pedon P1 (Oxic Dystrudepts from clay stone) | | | | | | | |
| 0 – 18 | + + + + | + | - | + + | + + | + | + |
| 40 – 73 | + + + + | + | - | + + | + + | + | + |
| 101 – 140 | + + + + | + | - | + + | + + | + | + |
| Pedon P2 (Typic Hapludox from andesitic rock) | | | | | | | |
| 0 – 15 | + + + + | - | + | + | + + | + + | - |
| 33 – 61 | + + + + | - | + | + | + + | + + | - |
| 88 – 124 | + + + + | - | + | + | + + | + + | - |
| Pedon P3 (Oxic Dystrudepts from ultra mafic rock) | | | | | | | |
| 0 – 16 | + + + + | - | - | + | + | + + | - |
| 64 – 112 | + + + + | - | - | + | + | + + | - |
| 148 – 160 | + + + + | - | - | + | + | + + | - |
| Pedon P4 (Anionic Acrudox from ultra mafic rock) | | | | | | | |
| 0 – 11 | - | - | + | + | + + | + + | - |
| 40 – 65 | - | - | + | + | + + | + + | - |
| 96 – 150 | - | - | + | + | + + | + + | - |
| Pedon P5 (Anionic Acrudox from lime stone) | | | | | | | |
| 0 – 21 | + | - | + + + | + + | + + + | + | - |
| 50 – 82 | + | - | + + + | + + | + + + | + | - |
| 123 – 150 | + | - | + + + | + + | + + + | + | - |
| Pedon P6 (Typic Kandiudox from lime stone) | | | | | | | |
| 0 – 17 | + + + + | - | + + | + | + + | + | - |
| 42 – 77 | + + + + | - | + + | + | + + | + | - |
| 104 – 123 | + + + + | - | + + | + | + + | + | - |

Note : + + + + = predominant, + + + = high, + + = moderate, + = low

Iron oxides in the LAC soils were identified as goethite, hematite, and magnetite. In the x-ray diffraction pattern (Figure 1), goethite was identified by main peaks 4.10 to 4.14Å and 2.19 Å, and hematite by peak 2.67 to 2.69 Å. Actually the main peak of goethite is 14.8 Å, a fact that the d-spacing of x-ray diffraction was smaller than usually found. It indicates that aluminum substitution for iron in soil goethite occurred. The aluminum substitution for iron in goethite is quite common. Due to the fact that $Fe^{3+}$ and $Al^{3+}$ have an identical valency and similar in size (r=0.76 Å for $Fe^{3+}$ and 0.67 Å for $Al^{3+}$), aluminum commonly substitutes for Fe in goethite. This condition is indicated by a shift to smaller d spacing of x-ray diffraction line. In general higher level of aluminum substitution occurred in goethite from highly weathered tropical and subtropical soils (Fitzpatrick and Schwertmann, 1982; Currie and Franzmeier, 1984; Schwertmann and Kampf, 1985).

Many oxide crystals in oxic horizons are so small in size that they have often been considered amorphous materials (Van Wambeke, 1991). Figure 1 shows the existence of amorphous iron oxide in the clay fraction. In this figure, sample without dithionite treatment shows more convex shape than sample with dithionite treatment indicating that amorphous form of iron oxide is present in the LAC soils.

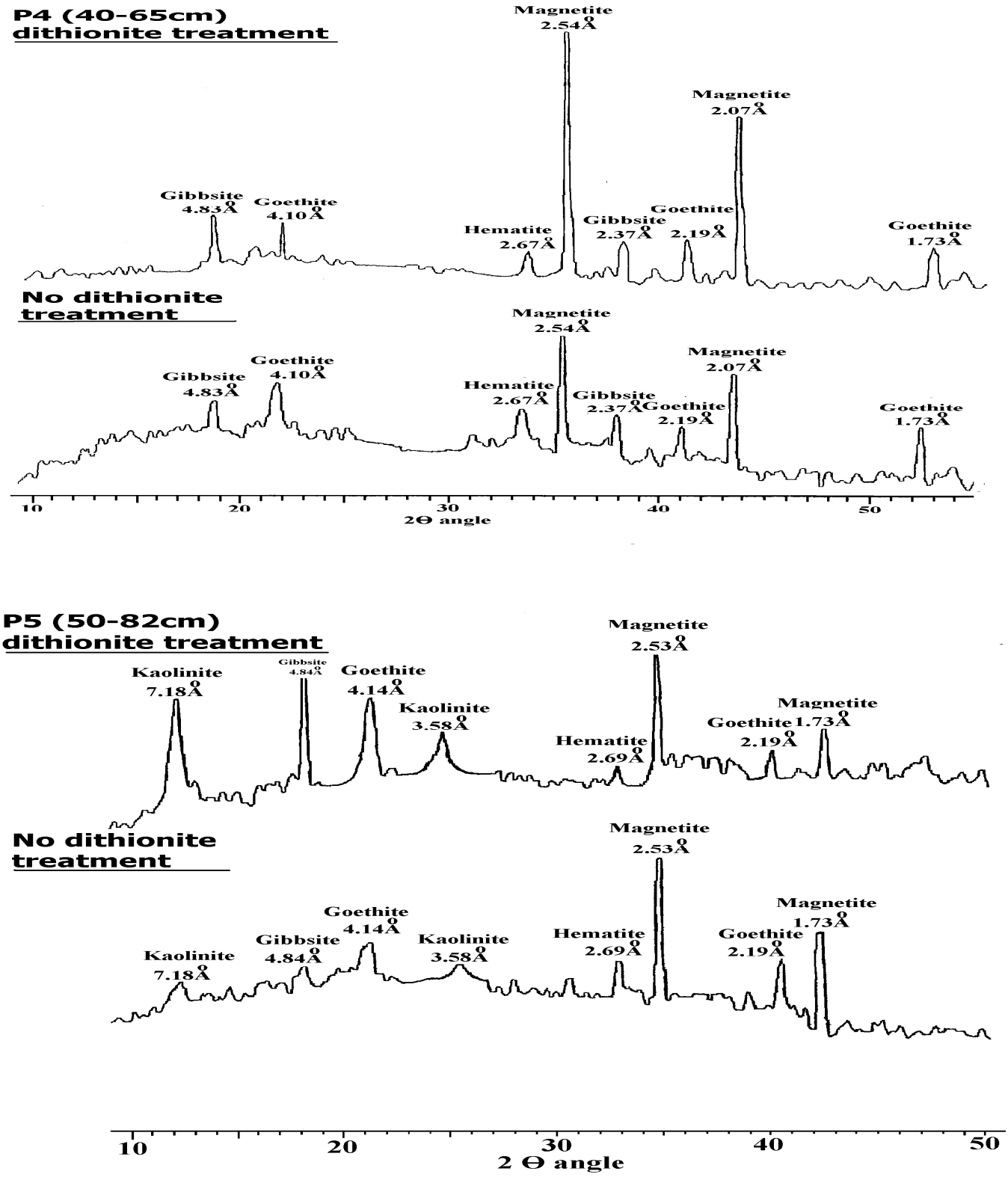


**Figure 1. X-ray diffraction pattern of clay fraction of pedons P4 (40 – 65 cm) and P5 ( 50–82 cm)**

*Gambar1. Pola difraksi sinar X dari fraksi liat pedon P4 (40-65cm) dan pedon P5 (50-82cm)*

Almost all studied soils especially LAC of Oxisols have friable consistency and granular to loose structures. Previous study declared that the presence of goethite and hematite influenced the properties of LAC soils. Geothite and hematite are stable iron oxide minerals in an oxidizing environment. Large amount of these two minerals in well-aerated soil indicates an advanced degree of weathering. At low pH reaction between positively charger iron oxide and permanently negative charged clay particles influenced soil structure, which was reflected in the soil consistency that were very friable and loose (Eswaran and Tavernier, 1980).

The LAC soils with soil color in the range of 7.5YR to 10R (yellowish red to red) indicated that the iron oxide minerals influenced their matrix color. It is generally accepted that the reddish color of the soils is related to the presence of iron oxides. Soil with color in the range of 2.5YR to 7.5YR contains goethite, and soil with 10R to 5YR color contains hematite (Eswaran and Sys, 1970). Goethite is thus responsible for the brownish and yellowish (Schulze, 1989), yellowish-brown to brown (Allen and Hajek, 1989), and yellowish to brown colors (Schwertmann and Taylor, 1989) of many soils. Hematite is responsible for the red color of many soils (Schulze, 1989).

The presence of magnetite is indicated by strong XRD intensities with d-spacing at 2.54Å and 2.07Å. Magnetite is a primary Fe oxide mineral especially in soil derived from basic rock. In the sand fraction, the presence of magnetite can only be identified as opaque mineral (Table 1), and the opaque mineral, especially in pedons P2, P4 and P5, may possibly be as magnetite. The presence of magnetite in the clay fraction also indicates an advanced stage of soil weathering.

Gibbsite was identified by a peak at 4.10 to 4.40 Å. Gibbsite can be formed directly from primary aluminum silicates or from a primary aluminum silicate via the formation of clay minerals as intermediates. Considering an advanced stage of LAC soil weathering, the gibbsite here is formed from desilisification process of clay minerals. In LAC soils gibbsite, is generally associated with the latter stage of weathering, when leaching of Si has progressed to such an extent that phyllosilicate minerals no longer form. Irrespective of whether gibbsite directly formed from primary aluminum silicates or via clay minerals, gibbsite formation is governed by the intensity of leaching which is affected by a number of factor such as rainfall, temperature, parent rock, topography, ground water table position, vegetation and time (Hsu, 1989). It has a very low CEC and contributes to the low native fertility of LAC soils.

The presence of small amount of vermiculite and quartz in the pedon P1 may indicate that the claystone as parent material of the soils is acid. Vermiculite indicate by diffraction peak at 14.2 Å and quartz is indicate by diffraction peaks at 4.26 Å and 3.34 Å.

**Chemical properties**

Almost all pedons have a heavy clay texture, with clay fraction ranges from 65 to 95% (Table 4). The clay content in P4 is possibly not a real value of clay fraction. The facts that silt and sand fraction contents are relatively high, soil have the most red color (10 R), and this pedon is developed from ultramafic rock that theoretically relatively easy to weather, show that pseudo sand or silt may have occurred in this pedon. The iron oxyhydrate has a binding effect on the clay to form pseudo sand (Eswaran and Tavernier, 1980).

In general, LAC soils exhibit very acid reaction (pH($H_2O$) 5.3-3.99) in both topsoil and subsoil, and under this condition exchangeable Al is present (except for soil derived from ultramafic rock and lime stone; pedons P4 and P5). The difference between pH in electrolyte (pH KCl) and pH in water (pH $H_2O$), usually called as $\Delta$pH, can be used to indicate the charge characteristics of the soils. Values of $\Delta$pH that are positive, zero or slightly negative (less than –0.5) generally indicate that soil is dominated by variable charge minerals (Uehara and Gillman, 1981). The $\Delta$pH data in Table 4 show

positive, zero, and negative values of less than -0.5. These conditions indicate that LAC soils are dominated by variable charge mineral. It means that LAC soils investigated are highly weathered, intensively leached, and infertile. As the consequences, the pH and buffering effect of LAC soils are either directly or indirectly related to variable charge phenomena and these soils need to be managed differently from soils with constant charge due to their differences in chemical and physical properties (Parfitt, 1980; Fox, 1980).

Organic matter in the term of organic carbon content was low to very high in topsoil, but very low in subsoil. The role of organic matter is almost the same between LAC soils classified as Oxisols (P2, P4 and P5) and Inceptisols (P1 and P3). The organic carbon tends to influence the cation exchange capacity of the soils (Figure 2). The simple regression also indicated that in LAC of Oxisols, organic carbon contributed 54% to their CEC, while in LAC of Inceptisols the contribution of organic carbon was 50%. These facts indicate that the organic matter is important in LAC Oxisols and Inceptisols. Generally the contribution of organic matter to the CEC of some Indonesian Oxisols is in the range between 84 to 89% (Prasetyo *et al.*, 1999).

Potential P content (25% HCl), expressed as mg $P_2O_5$ per 100g soil, ranged from very low to very high. The lowest potential P content is shown by pedons P4 and P6, and the highest potential P content is shown by pedon P5. Available P (Bray method) in almost all pedons was very low, except for pedon P5, which was moderate. The LAC soils showed low native P status and P deficiency. P retention ranged from high to very high in all pedons. The high P fixing capacity is one of the characteristics of LAC soils. Previous studies indicated that some soil characteristics may affect P retention. Among of them are organic matter, amount and type of clay minerals (Sanchez and Uehara, 1980), extractable Fe and Al oxides (Araki *et al.,* 1986; Prasetyo *et al.,* 2001).

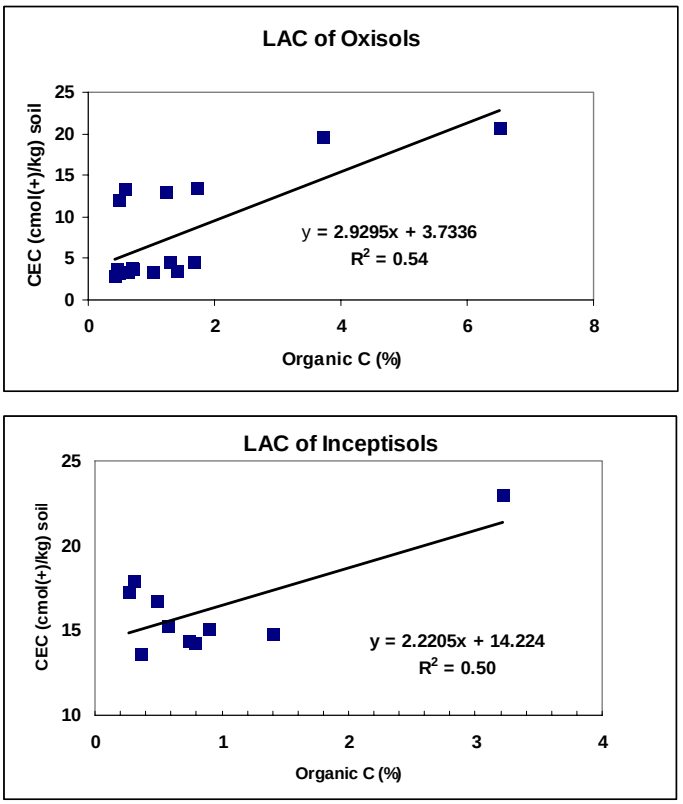


**Figure 2. Relationship between soil CEC and organic-C of LAC soils, South Kalimantan**

*Gambar 2. Hubungan antara KTK tanah dan C-organik pada tanah-tanah berliat aktivitas rendah di Kalsel*

Exchangeable bases were very low for all pedons (Table 5) and no longer indicated their parent material. The advanced stage of soil weathering through leaching of bases generally occurred in Indonesian upland soils. The CEC and clay ranged from 3.29 to 23.02 cmol(+)$kg^{-1}$ soil and from 3.91 to 34.88 cmol(+)$kg^{-1}$ clay. The CEC clay value was calculated by formula: (CEC soil*100/clay content), so that the high value of CEC clay (119,20 cmol(+)$kg^{-1}$ ) in the topsoil of pedon P4 was caused by low content of clay fraction. The CEC of soil with variable charge is very dependent on the method used for its determination. The $NH_4OAc$ method gives values far in excess of the CEC at natural pH, because the amount of negative charge increases markedly with pH and with electrolyte concentration (Chan *et al.,* 1979).

**Table 4. Grain size distribution, pH, C and phosphate contents of LAC soils, South Kalimantan**

*Tabel 4. Sebaran besar butir, pH, C dan kandungan fosfat dari tanah berliat aktivitas rendah, Kalsel*

| Depth | Sand | Silt | Clay | $H_2O$ | KCl | ΔpH | C | HCl (25%) | | Bray 1 $P_2O_5$ | P Retention |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | $P_2O_5$ | $K_2O$ | | |
| cm | ..... % ..... | | | | | | % | mg/100 g | | ppm | % |
| Pedon P1 (Oxic Dystrudepts from clay stone) | | | | | | | | | | | |
| 0 – 18 | 8 | 22 | 70 | 4.00 | 3.56 | -0.44 | 1.4 | 34.67 | 19.75 | 1.16 | 48 |
| 18 – 40 | 8 | 10 | 82 | 4.01 | 3.57 | -0.44 | 0.89 | 28.89 | 17.12 | 1.79 | 46 |
| 40 – 73 | 7 | 22 | 71 | 4.05 | 3.57 | -0.48 | 0.74 | 31.26 | 14.76 | 0.59 | 50 |
| 73 – 101 | 7 | 22 | 71 | 3.99 | 3.70 | -0.29 | 0.58 | 29.74 | 8.64 | 0.90 | 50 |
| 101 – 140 | 9 | 24 | 67 | 4.00 | 3.70 | -0.30 | 0.36 | 35.54 | 8.52 | 0.89 | 52 |
| Pedon P2 (Typic Hapludox from andesitic rock) | | | | | | | | | | | |
| 0 – 15 | 2 | 13 | 85 | 4.36 | 3.85 | -0.51 | 3.71 | 24.23 | 6.39 | 2.37 | 56 |
| 15 – 33 | 1 | 13 | 86 | 4.43 | 3.98 | -0.45 | 1.72 | 19.86 | 4.17 | 0.87 | 65 |
| 33 – 61 | 2 | 14 | 84 | 4.31 | 4.04 | -0.27 | 1.22 | 21.16 | 4.10 | 0.57 | 68 |
| 61 – 88 | 1 | 13 | 86 | 4.23 | 4.06 | -0.17 | 0.8 | 18.68 | 3.31 | 0.31 | 68 |
| 88 – 124 | 2 | 15 | 83 | 4.65 | 4.04 | -0.61 | 0.58 | 17.62 | 4.16 | 0.58 | 74 |
| 124 – 151 | 2 | 16 | 82 | 4.23 | 4.05 | -0.18 | 0.49 | 16.79 | 4.23 | 0.59 | 75 |
| Pedon P3 (Oxic Dystrudepts from ultra mafic rock) | | | | | | | | | | | |
| 0 – 16 | 8 | 26 | 66 | 4.71 | 3.90 | -0.81 | 3.21 | 37.16 | 19.00 | 14.73 | 45 |
| 16 – 64 | 5 | 22 | 73 | 4.45 | 3.70 | -0.75 | 0.79 | 21.28 | 8.69 | 1.88 | 57 |
| 64 – 112 | 11 | 6 | 83 | 4.29 | 3.80 | -0.49 | 0.49 | 22.66 | 4.39 | 1.27 | 60 |
| 112 – 148 | 5 | 11 | 84 | 4.50 | 3.70 | -0.80 | 0.31 | 22.10 | 4.28 | 1.24 | 65 |
| 148 – 160 | 5 | 10 | 85 | 4.29 | 3.80 | -0.49 | 0.27 | 40.67 | 4.33 | 1.25 | 63 |
| Pedon P4 (Anionic Acrudox from ultra mafic rock) | | | | | | | | | | | |
| 0 – 11 | 27 | 56 | 17 | 6.30 | 6.10 | -0.20 | 6.52 | 19.23 | 11.01 | 34.31 | 70 |
| 11 – 40 | 9 | 71 | 20 | 5.18 | 5.60 | 0.42 | 1.39 | 10.43 | 4.15 | 0.60 | 87 |
| 40 – 65 | 29 | 56 | 15 | 5.15 | 6.00 | 0.85 | 0.7 | 10.67 | 4.24 | 0.61 | 92 |
| 65 – 96 | 19 | 60 | 21 | 5.05 | 6.10 | 1.05 | 0.42 | 10.89 | 3.25 | 1.25 | 94 |
| 96 – 150 | 13 | 61 | 26 | 5.30 | 6.20 | 0.90 | 0.51 | 8.48 | 3.20 | 0.62 | 94 |
| Pedon P5 (Anionic Acrudox from lime stone) | | | | | | | | | | | |
| 0 – 21 | 4 | 1 | 95 | 5.17 | 4.90 | -0.27 | 2.75 | 31.82 | 6.68 | 10.28 | 58 |
| 21 – 50 | 5 | 3 | 92 | 4.85 | 5.30 | 0.45 | 1.28 | 58.31 | 2.20 | 19.07 | 65 |
| 50 – 82 | 6 | 2 | 92 | 4.96 | 5.60 | 0.64 | 0.72 | 67.22 | 2.13 | 19.09 | 72 |
| 82 – 123 | 5 | 2 | 93 | 5.21 | 5.80 | 0.59 | 0.44 | 74.41 | 2.05 | 20.13 | 72 |
| 123 – 150 | 3 | 3 | 94 | 5.27 | 5.90 | 0.63 | 0.49 | 60.66 | 2.18 | 17.01 | 69 |
| Pedon P6 (Typic Kandiudox from lime stone) | | | | | | | | | | | |
| 0 – 17 | 19 | 16 | 65 | 4.80 | 4.30 | -0.50 | 1.67 | 5.43 | 4.00 | 8.89 | 43 |
| 17 – 42 | 16 | 10 | 74 | 4.40 | 4.30 | -0.10 | 1.03 | 3.88 | 2.10 | 3.63 | 55 |
| 42 – 77 | 14 | 8 | 78 | 4.90 | 4.50 | -0.40 | 0.7 | 4.65 | 2.19 | 1.90 | 65 |
| 77 – 104 | 13 | 18 | 69 | 4.50 | 4.40 | -0.10 | 0.63 | 4.61 | 2.17 | 0.63 | 68 |
| 104 – 123 | 12 | 5 | 83 | 4.50 | 4.50 | 0.00 | 0.48 | 3.76 | 2.03 | 1.17 | 71 |
| 123 – 150 | 11 | 9 | 80 | 4.50 | 4.50 | 0.00 | 0.49 | 4.23 | 2.28 | 1.32 | 66 |

**Table 5. Exchangeable bases, cation exchange capacity, exchangeable acidity, aluminum saturation, and free iron of LAC soil, South Kalimantan**

*Tabel 5. Basa-basa dapat tukar, kapasitas tukar kation, kemasaman dapat tukar, kejenuhan aluminum, dan besi bebas dari tanah-tanah berliat aktivitas rendah, Kalsel*

| Depth | Exchangeable Cation | | | | | Cation Exchange Capacity | | Exchangeable Acidity | | Al saturation | Free $Fe_2O_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ca | Mg | K | Na | Sum | Soil | Clay | Al | H | | |
| cm | ..... cmol(+)$kg^{-1}$soil ..... | | | | | | | | | % | % |
| Pedon P1 (Oxic Dystrudepts from clay stone) | | | | | | | | | | | |
| 0 – 18 | 0.37 | 0.31 | 0.33 | 0.00 | 1.01 | 14.80 | 21.14 | 7.47 | 0.93 | 88 | 5.72 |
| 18 – 40 | 0.33 | 0.22 | 0.32 | 0.00 | 0.87 | 15.09 | 18.4 | 8.52 | 1.01 | 90 | 5.40 |
| 40 – 73 | 0.32 | 0.32 | 0.29 | 0.00 | 0.93 | 14.39 | 20.27 | 8.66 | 1.08 | 90 | 5.71 |
| 73 – 101 | 0.28 | 0.24 | 0.08 | 0.00 | 0.60 | 15.28 | 21.52 | 8.83 | 1.06 | 93 | 6.24 |
| 101 – 140 | 0.22 | 0.32 | 0.06 | 0.00 | 0.60 | 13.59 | 20.28 | 7.66 | 0.96 | 92 | 6.48 |
| Pedon P2 (Typic Hapludox from andesitic rock) | | | | | | | | | | | |
| 0 – 15 | 1.74 | 1.22 | 0.13 | 0.05 | 3.14 | 19.60 | 23.06 | 2.61 | 0.54 | 45 | 7.70 |
| 15 – 33 | 1.01 | 0.65 | 0.04 | 0.03 | 1.73 | 13.57 | 15.78 | 2.34 | 0.53 | 57 | 7.76 |
| 33 – 61 | 0.89 | 0.48 | 0.02 | 0.00 | 1.39 | 13.03 | 15.51 | 1.88 | 0.51 | 57 | 7.38 |
| 61 – 88 | 0.39 | 0.61 | 0.02 | 0.00 | 1.02 | 13.47 | 15.66 | 2.07 | 0.51 | 67 | 9.86 |
| 88 – 124 | 0.37 | 0.58 | 0.02 | 0.06 | 1.03 | 13.31 | 16.04 | 2.34 | 0.52 | 69 | 8.38 |
| 124 – 151 | 0.49 | 0.53 | 0.02 | 0.00 | 1.04 | 11.97 | 14.6 | 1.56 | 0.49 | 59 | 8.13 |
| Pedon P3 (Oxic Dystrudepts from ultra mafic rock) | | | | | | | | | | | |
| 0 – 16 | 7.28 | 3.18 | 0.40 | 0.03 | 10.89 | 23.02 | 34.88 | 1.30 | 0.31 | 10 | 6.47 |
| 16 – 64 | 0.94 | 0.88 | 0.17 | 0.15 | 2.14 | 14.25 | 19.52 | 7.12 | 0.99 | 79 | 6.70 |
| 64 – 112 | 0.39 | 0.61 | 0.09 | 0.13 | 1.22 | 16.76 | 20.19 | 8.34 | 0.99 | 87 | 7.27 |
| 112 – 148 | 0.33 | 0.59 | 0.08 | 0.24 | 1.24 | 17.88 | 21.29 | 9.79 | 1.06 | 88 | 5.82 |
| 148 – 160 | 0.28 | 0.60 | 0.09 | 0.05 | 1.02 | 17.25 | 20.29 | 9.55 | 0.98 | 90 | 5.76 |
| Pedon P4 (Anionic Acrudox from ultra mafic rock) | | | | | | | | | | | |
| 0 – 11 | 15.12 | 2.00 | 0.15 | 0.07 | 17.34 | 20.27 | 119.2 | 0.00 | 0.00 | 0 | 8.53 |
| 11 – 40 | 0.90 | 0.09 | 0.02 | 0.00 | 1.01 | 5.12 | 25.6 | 0.00 | 0.00 | 0 | 8.70 |
| 40 – 65 | 0.49 | 0.05 | 0.02 | 0.00 | 0.56 | 3.62 | 24.13 | 0.00 | 0.00 | 0 | 8.61 |
| 65 – 96 | 0.39 | 0.05 | 0.02 | 0.00 | 0.46 | 3.84 | 18.29 | 0.00 | 0.00 | 0 | 8.29 |
| 96 – 150 | 0.38 | 0.05 | 0.02 | 0.00 | 0.45 | 2.88 | 11.08 | 0.00 | 0.00 | 0 | 8.57 |
| Pedon P5 (Anionic Acrudox from lime stone) | | | | | | | | | | | |
| 0 – 21 | 2.67 | 0.69 | 0.11 | 0.00 | 3.47 | 13.69 | 14.41 | 0.00 | 0.00 | 0 | 8.49 |
| 21 – 50 | 1.07 | 2.13 | 0.02 | 0.00 | 3.22 | 6.18 | 6.71 | 0.00 | 0.00 | 0 | 8.77 |
| 50 – 82 | 0.82 | 0.23 | 0.02 | 0.00 | 1.07 | 4.55 | 4.94 | 0.00 | 0.00 | 0 | 9.31 |
| 82 – 123 | 0.89 | 0.26 | 0.02 | 0.00 | 1.17 | 3.69 | 3.96 | 0.00 | 0.00 | 0 | 7.48 |
| 123 – 150 | 0.95 | 0.33 | 0.02 | 0.02 | 1.32 | 3.68 | 3.91 | 0.00 | 0.00 | 0 | 8.56 |
| Pedon P6 (Typic Kandiudox from lime stone) | | | | | | | | | | | |
| 0 – 17 | 1.21 | 0.79 | 0.06 | 0.00 | 2.06 | 6.58 | 10.12 | 0.50 | 0.13 | 19 | 6.32 |
| 17 – 42 | 0.43 | 0.28 | 0.02 | 0.00 | 0.73 | 4.62 | 6.24 | 0.58 | 0.15 | 44 | 6.55 |
| 42 – 77 | 0.73 | 0.17 | 0.00 | 0.00 | 0.90 | 3.41 | 4.37 | 0.04 | 0.02 | 5 | 7.50 |
| 77 – 104 | 0.56 | 0.20 | 0.00 | 0.00 | 0.76 | 3.84 | 5.56 | 0.07 | 0.02 | 8 | 7.39 |
| 104 – 123 | 0.67 | 0.17 | 0.00 | 0.00 | 0.84 | 3.30 | 3.97 | 0.00 | 0.00 | 0 | 6.35 |
| 123 – 150 | 0.70 | 0.17 | 0.00 | 0.00 | 0.87 | 3.29 | 4.11 | 0.00 | 0.00 | 0 | 8.88 |

The content of exchangeable Al, H, and the value of Al saturation are considered very high in LAC soils derived from claystone, high in LAC soils from andesite, and almost undetectable in LAC soils from ultramafic and limestone. The role of parent material is important in the exchangeable acidity of the soils. The weathering processes in soil derived from claystone and andesitic rock release aluminum more than that weathering of ultramafic and limestone. The claystone and andesitic rock are acid to slightly acid and rich in source of Al, while the ultramafic rock and limestone are alkaline and poor of Al.

Differences in these properties would also affect their agronomic management. At low pH, the Al is present in the exchange complex and diffuses in the soil solution where it may cause toxicities for LAC of soils. Liming is useful to eliminate the aluminum toxicity that impairs root development, and consequently reduce the nutrient and water uptake by plant. The liming also increases soil pH, Ca, and reduces phosphate fixation.

Free iron content was considered high for all pedons. Reddish soil color in all pedons indicated that the soil have a high iron oxide. It was assumed that the high content of free iron is related to high P retention of the LAC soils. The relationship between P retention and free iron is shown in Figure 3.

## UTILIZATION OF LAC SOILS

LAC soils were dominated by opaque and quartz as resistant primary minerals in their sand fraction, and kaolinite, gibbsite, magnetite, goethite, and hematite in the clay fraction. The mineralogical composition indicated an advanced stage of soil weathering and low potential nutrient reserve of the soils. The soils were very acid and most plant nutrients were concentrated in shallow topsoils, associated with organic matter that very fragile towards erosion and decomposition process. As the consequences, the LAC soils, in which variable charge is predominant, are infertile in the extreme, and the fertilization is necessary for sustainable use.

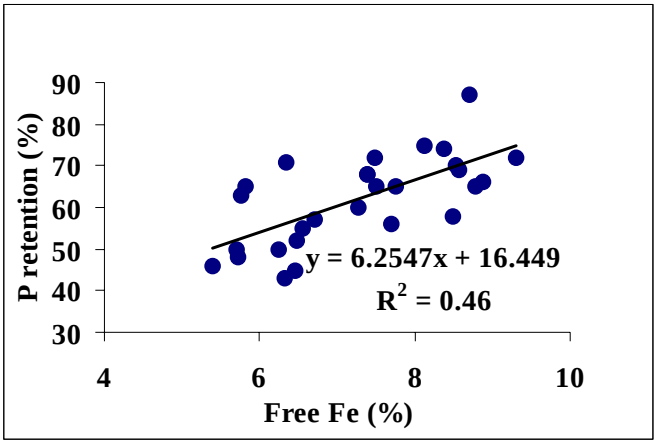


**Figure 3. Relationship between P retention and free iron of LAC soils, South Kalimantan**

*Gambar 3. Hubungan antara retensi P dan besi bebas pada tanah-tanah berliat aktivitas rendah, Kalsel*

Some of LAC soils investigated have a positive charge. To develop a negative charge (CEC), addition of organic materials is needed to increase the soil organic matter content. The organic matter is a source of nitrogen and releases P through mineralization process, but it also blocks anion adsorption site on the clay that phosphorous may retain too strongly for plant uptake (Van Wambeke, 1991). Contribution of organic matter in LAC of Oxisols is relatively more important than in LAC of Inceptisols, due to the extremely low CEC of the mineral fraction of the oxic horizon. A green house experiment by Anda *et al.* (2001), reported that application of P, lime, basic slag, and organic matter is able to manipulate colloidal charge surfaces having positive charges to become negative and the less low negative charge of colloidal surfaces become more negative.

High P retention is another constraint on the LAC soils. Most oxic horizons react with phosphate ions in such a way that they either adsorb them or

chemically bind them on sesquioxide surface of the clay (Van Wambeke, 1991). Some soils retain phosphate so tightly that they make little of it available to plant. Normally, a concentration of 0.2 mg P/L soil solution is adequate enough for a number of crops (Juo, 1981). To solve P fixation constraint, in capital-intensive system, it is often advised to block the positive charge of the soils by large initial broadcast application of P fertilizers (Van Wambeke, 1991). Organic matter may also mask the effect of positive adsorption site.

Annual crop plantation that leave the soil surface bare for an extended period of time is an inappropriate management of LAC of Oxisols. The crumb, friable, and granular soil structure of LAC Oxisols, is very easy to be eroded by rain drop and runoff. Instead, tree crops are ecologically best suited. They protect the land against raindrops impact, and their root systems are permanently exploring a large volume of soil to tap nutrients and to overcome short drought periods.

Kang and Triparthi (2002) suggested that integrated soil fertility management for LAC soils can be achieved by various methods including more efficient uses of nutrients from plant and organic residues to reduce soil acidity problem, local source of phosphate, and acid tolerant cultivar.

## CONCLUSIONS

1. Domination of resistant minerals such as opaque and quartz; the present of gibbsite, goethite, hematite, and magnetite; and low nutrient content indicate that the LAC soils from South Kalimantan have an advanced stage of soil weathering and low potential nutrient reserve. As the consequence, the LAC soils in which variable charge is predominant are extremely infertile.
2. Low nutrient content and low pH, high P fixing capacity, and low cation exchange capacity are the main constraint of the LAC soils from South Kalimantan. High aluminum saturation is also a problem for LAC soils derived from claystone, but not for those derived from ultramafic rock and limestone.
3. For a sustainable use of the LAC soils, selective plantation and a complete amelioration, such as organic matter and liming application, should be considered.

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